Final Report on

Multiple Scale Methods for Compressible Viscous Fluid-Structure Interaction

From May 1, 1996 – September 30, 1999

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AFOSR Grant Number F49620-96-1-0171

1 Objectives

Fluid-structure interaction, a multiscale problem in nature, often involves complex physical phenomena such as energy transfer between fluids and solids, oscillating shock and boundary layers, and nonlinear dynamic instabilities, is a crucial issue in aircraft design. Because the coupling effects between aerodynamic forces and elastic bodies have a significant impact on aircraft performance and safety issues, a complete understanding of this coupling has been pursued in order to improve capabilities for predicting critical flight loads.

Fluid-structure loading needs to be accurately predicted for a wide spectrum of frequencies and wave numbers, requiring resolution of many different scales, both spatial and temporal. A reliable computer simulation of fluid-structure interaction is important for the characterization of the system and will allow the prediction of crack propagation and fatigue reliability (Figure 1). All of this is an indispensable element of cost-effective decision making.

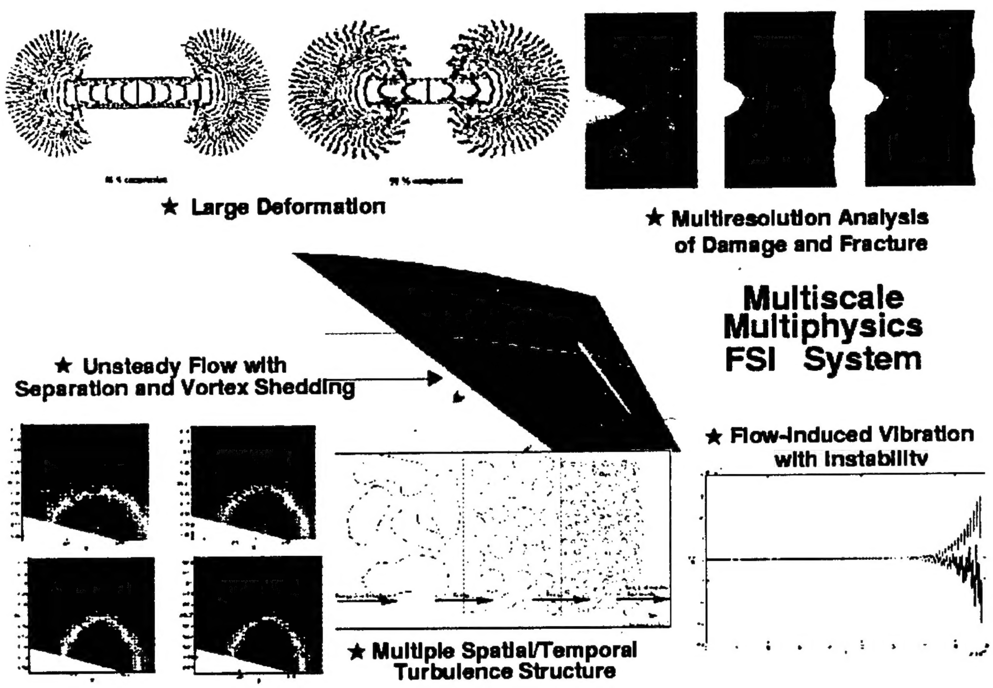


Figure 1: Scope of Research

2 Technical Approach

Since fluid-structure interaction requires solid mathematical modeling of the various physical phenomena of solids/structure and fluids, our research efforts have been focused on the development of multiple scale Reproducing Kernel Particle Methods (RKPM), which possess a few remarkable technical advantages from a computational mechanics point of view, such as mesh-free interpolation functions and superior accuracy and convergence rate with stabilization. Most importantly, with the inherent multiresolution analysis capability, RKPM is used to further investigate the physical nature of fluid-structure in-

teraction problems in a way that the system response can be decomposed into multiple frequency/wave number bands for a better representation of the computed physics.

3 Accomplishments/Key Contributions

3.1 Computational Fluid Dynamics

3.1.1 Large-scale detailed simulation of unsteady flows involving separation and vortex shedding

A better understanding of complex flow patterns such as flow separation and vortex shedding is achieved, as a result of our detailed simulation of unsteady flow passing a NACA airfoil. Figure 2 shows the streamlines and velocity vectors in the vicinity of the airfoil. The flow separates from the airfoil behind mid-length. A vortex is observed close to the airfoil tail. Figure 3 shows the evolution of the vortex. This unsteady flow phenomenon proves that the current practice of fluid-structure interaction modeling which has obstacles in catching these small physical scales. In addition, it is not adequate enough due to the ever-changing nature of pressure distribution acting on the airfoil. It is believed that this large-scale detailed simulation demonstrates enhanced computational fidelity which offers great potential for a better modeling of fluid-structure interaction and may lead to significant reduction of wind tunnel tests. With an introduction of a proper turbulence model (to be developed together with Mr. Gregory Wagner, who is currently being sponsored by a 3-year DoD fellowship), phenomena like these could be further examined to shed light on the fundamental nature of fluid-structure interaction problems.

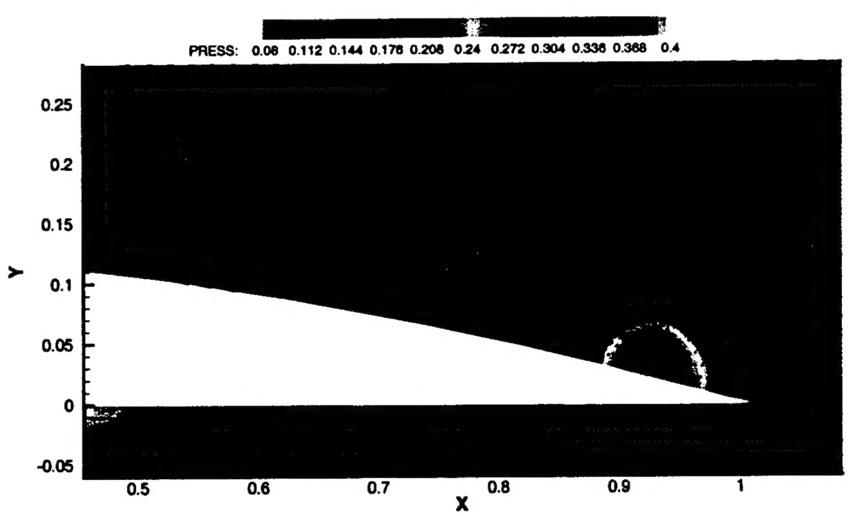


Figure 2: Streamlines in flow separation region

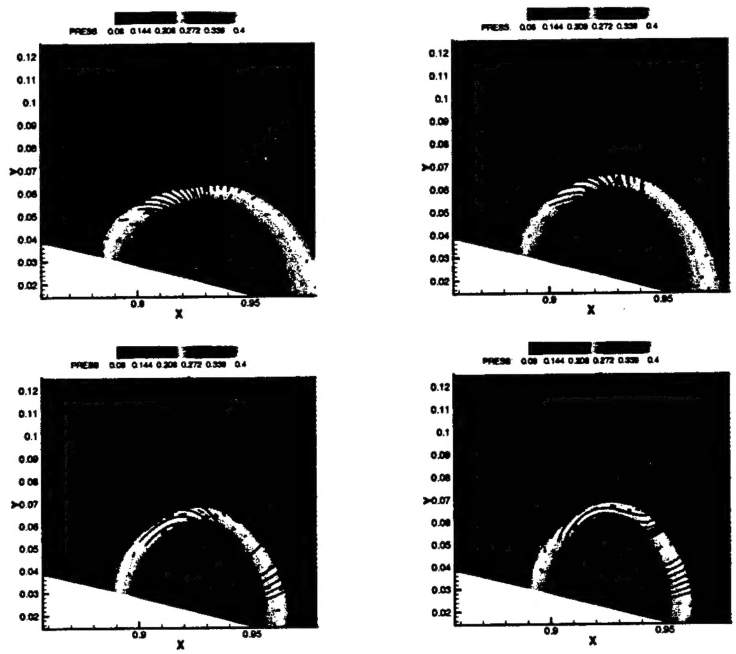


Figure 3: Development of a vortex for unsteady flow

3.1.2 Large Eddy Simulation (LES) of turbulence

Turbulent fluid flow poses a special difficulty in CFD because of the wide range of spatial and temporal scales present. In general, resolving all of these scales on a computational grid is prohibitively expensive for any flow complex enough to be of engineering interest. One approach to this problem which has come to the forefront over the last two decades is large eddy simulation (LES). In LES, the large and moderate scales in a flow are simulated directly. The effects of the small scales, which interact nonlinearly with the large scales, must be modeled.

When RKPM is used in LES, the multiple scale decomposition of the computed flow field can serve as a basis for this model. Because of the self-similarity of the flow, the smallest resolved scales are assumed to be similar to the unresolved scales. Enforcing this similarity leads to an added viscosity in the equations of motion, which dissipates energy in a way mimicking that of the missing small scales.

The resulting model is currently being evaluated in the simulation of isotropic turbulence. Figure 4 shows the evolution of regions of positive and negative x-vorticity in a periodic cell. Figure 5 shows behavior of the energy density spectrum $E(k)$. Once the model has been verified in this simulation, it will be applied to more complicated geometries and conditions.

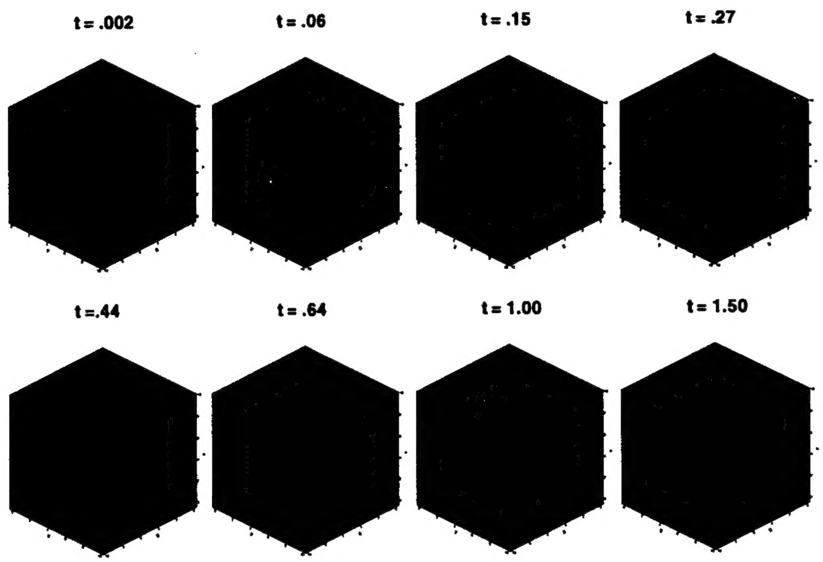


Figure 4: Positive/negative x-vorticity, isotropic turbulence

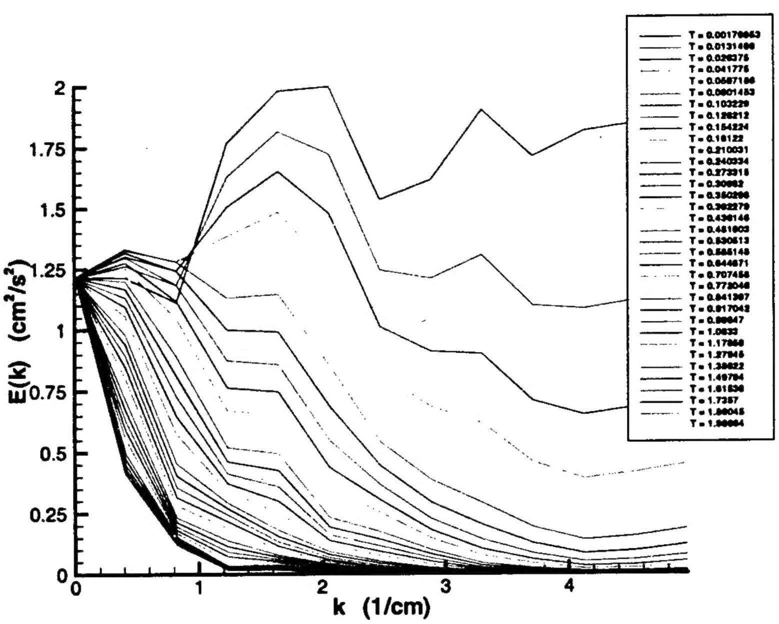
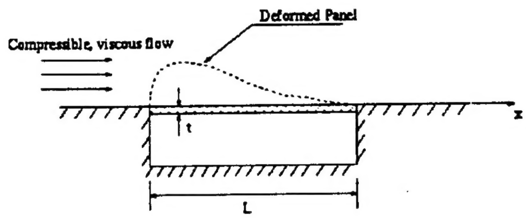


Figure 5: Energy density spectrum, isotropic turbulence

3.2 Hierarchical Modeling of Fluid-Structure Coupled System

A hierarchical modeling of fluid-structure coupled system is being constructed starting from the coarse scale to the fine scale. Panel flutter, a typical fluid-structure interaction phenomenon, is used as an example to demonstrate the sequence of hierarchical modeling (Figure 6). Eigenanalysis of the linear panel coupled with first-order piston theory determines the flutter boundary (critical dynamic pressure $q_{cr} = 340$) beyond which the panel motion becomes unstable. After accounting for the structural nonlinearities resulting from large deflection, a higher critical dynamic pressure ($q_{cr} = 410$) is obtained. When a more suitable fluid model is applied (Euler equation), the instability occurs at a even higher critical value ($q_{cr} = 419$). The discrepancies between critical dynamic pressures obtained at different level of modeling prove that structural nonlinearities and viscous flow effects need to be accounted for a comprehensive description of the physical nature. At the present time, we are in the process of completing this hierarchical fluid-structure interaction model based on multiscale meshfree methods described in the previous subsection. However, further development is necessary.



- linear structure with first-order piston theory (Dowell)

$$\boxed{D\frac{\partial^4 w}{\partial x^4} + m\frac{\partial^2 w}{\partial t^2} = p(x,t)} \qquad \boxed{q_{cr} = 340}$$

q_{cr} is the non-dimensional critical dynamic pressure ($q = \rho V^2 L^3/(\sqrt{M^2-1}D)$)

- non-linear structure (Dowell, Mei)

$$\boxed{D\frac{\partial^4 w}{\partial x^4} - N_x\frac{\partial^2 w}{\partial x^2} + m\frac{\partial^2 w}{\partial t^2} = p(x,t)} \qquad \boxed{q_{cr} = 410}$$

- Euler flow passing a thin plate $\boxed{q_{cr} = 419}$

- Compressible, viscous flow with largely deformed structure $\boxed{q_{cr} = ?}$

- Turbulence-structure interaction $\boxed{q_{cr} = ??}$

Figure 6: Hierarchical modeling of panel flutter

3.3 Multiscale Meshfree Methods for Fluids and Solids

In a fluid-structure coupled system, the structure is often largely deformed and under high frequency periodic loading conditions, the alternated stress-strain peaks may cause evolution of damage in the form of microcracks which will result in macro fatigue crack growth and lead to the final failure of the structure. To circumvent the usual difficulties encountered in classical mesh-based methods, such as mesh distortion, the need for remeshing, multiscale meshfree methods are being developed.

Figure 7 shows the deformation of a block of hyperelastic material under compression. The traditional finite element analysis failed when the compression percentage reaches 66% due to severe mesh entanglement while the meshfree Reproducing Kernel Particle Methods (RKPM) can go as far as 90% when the material is in contact with the rigid surfaces. The absence of a remeshing procedure highlights the unique merit of this new type of meshfree methodology.

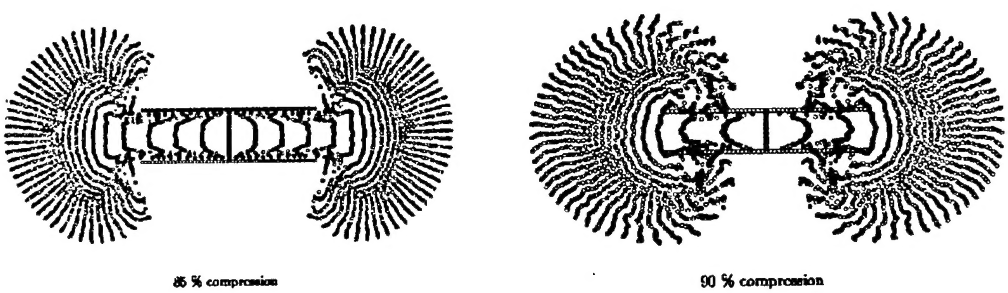


Figure 7: Hyperelastic block under compression

The inherent multiresolution analysis feature has proven to be useful from both physical and computational perspectives. It offers additional information about the physics of the simulated model, and can concentrate solution efforts in high-scale regions.

We have successfully employed the concept of multiresolution analysis to predict the various scales of fluids and solids. For fluids, shocks and boundary layers are essential features in transonic and supersonic flow regimes. Knowledge of their location is necessary for a better understanding of fluid-structure interaction. High-gradient areas in structural deformation also need to be identified.

Two representative examples of multiresolution analysis are shown in Figure 8 and 9. The left-hand side picture depicts the comparison of total scale solution and high scale solution for the pressure distribution. The high scale solution clearly indicates the shock location and can be used as an error indicator to guide the adaptivity which is simply implemented by the addition of appropriately placed particles in the meshfree methods. A similar application to large deformation solids and shear bands is illustrated in the right-hand side picture. It is noted that the high scale solution captures the location of the shear band as well as the refinement region in the notch-bend specimen. The extension of the scope of this research to include fluid-structure interaction problems is underway.

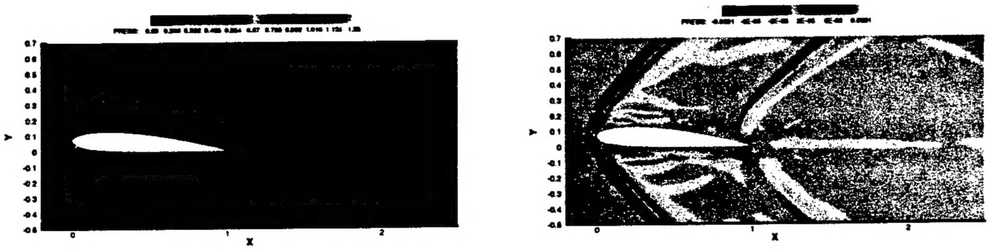


Figure 8: Multiresolution analysis in fluids

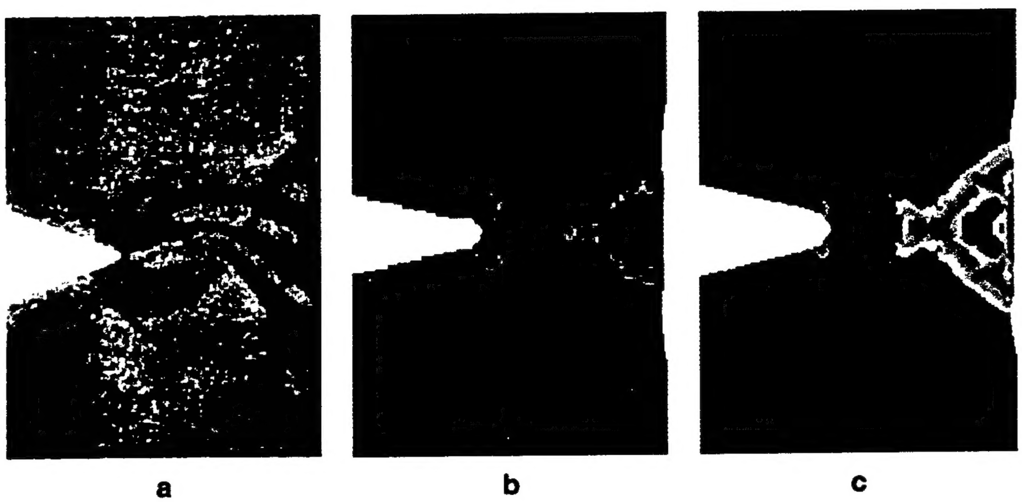


Figure 9: Multiscale analysis localization of the shear band: (a) Luders bands, (b) total scale solution, and (c) high scale solution

3.4 Total Arbitrary Lagrangian Eulerian Formulation

In free boundary problems, using Arbitrary Lagrangian Eulerian (ALE) method offers the advantage to move continuously the mesh of the domain as the free boundary moves, thus avoiding any mesh collapsing or frequent remeshings. Moreover, comparing with the conventional ALE formulations, using total ALE formulation provides the convenience of calculating the equations in the referential domain. A brief summary of the governing equation using moving particle formulation is presented below. Note that all the partial derivatives are taken respective to χ, the referential coordinate system:

$$\hat{\rho}_{,t} + (\hat{\rho} w_j)_{,j} = 0 \qquad \text{mass} \qquad (1a)$$

$$(\hat{\rho} u_i)_{,t} + (\hat{\rho} w_j u_i)_{,j} + \hat{p}_{,i} = \tau_{ij,j} + \hat{\rho} b_i \qquad \text{momentum} \qquad (1b)$$

$$(\hat{\rho} e)_{,t} + (\hat{\rho} w_i e)_{,i} + (\hat{p} u_i)_{,i} = (\tau_{ij} u_j)_{,i} - q_{i,i} + \hat{\rho} b_j u_j + \hat{\rho} r \qquad \text{energy} \qquad (1c)$$

where density $\hat{\rho}(\chi, t) = \hat{J}\rho(\mathbf{x}, t)$ and $\hat{J} = det(\frac{\partial \mathbf{x}}{\partial \chi})$;
u_i are the velocity components;
$w_i = \frac{\partial \chi_i}{\partial t} |_X$ is the particle velocities in the referential coordinates;
$\hat{p}$ is the thermodynamic pressure;
τ_{ij} is the stress tensor;
b_i is the body force vector;
e is the total energy density;
q_i is the heat flux vector;
and r is the heat source.

In this moving particle formulation, the governing equations (Eq.1) are similar to those of Arbitrary Lagrangian Eulerian (ALE) equations. However, this total ALE formulation ensures that the deforming particles conform to both stationary and moving boundaries. Within the interior of the fluid domain, particle movement can be modeled by the equations of large deformation elasticity which computes the updated position of the interior particles and sets the positions and velocities of the boundary particles to match the boundary motions.

We have primirily tested the above set of Navier-Stoke's equations using the finite element method for a 3-D flow past an oscillating cylinder example.

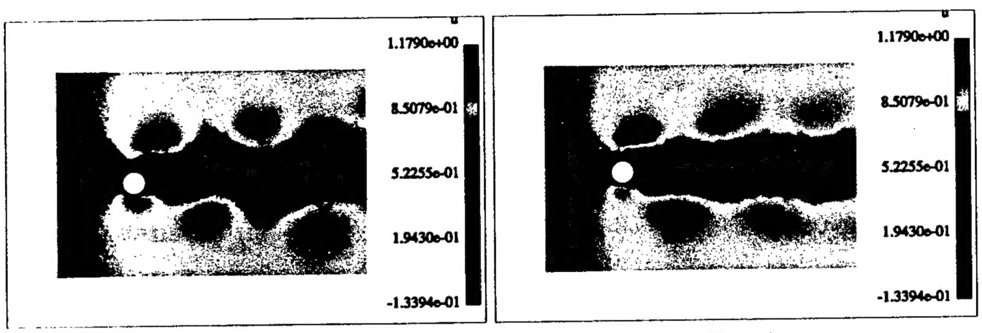


Figure 10: Time history of velocity in x-direction

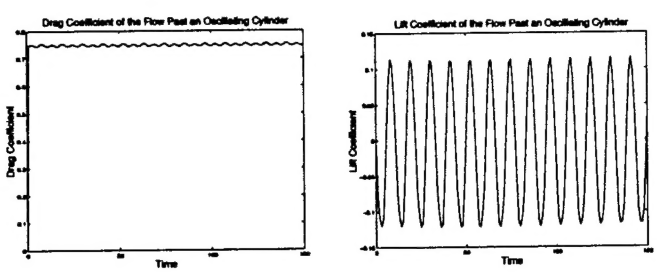
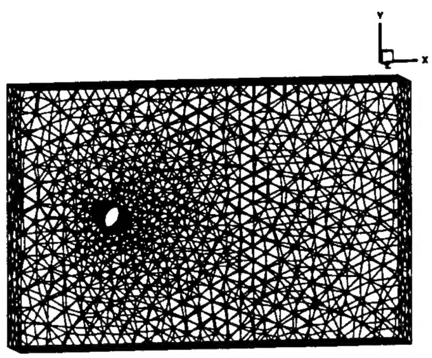


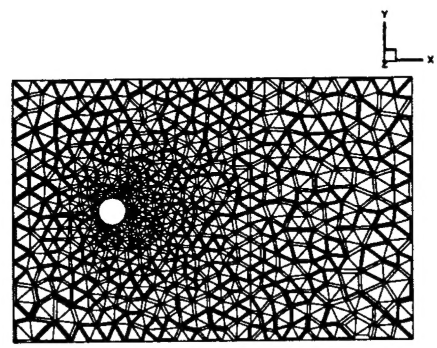
Figure 11: Time history of drag and lift coefficients at Re=100

4 Future Work

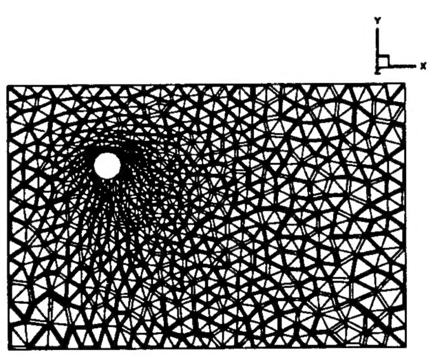
Fluid-structure interaction problems often require the movement (or update) of the computational domain in response to large deformation, flow separation etc. Thus a meshfree moving particle method, which is based on the deformation gradient of the particles' motion, is utilized to account for the deformation. One of the most significant advantages of meshfree methods is that it requires only particles and no element connectivity is needed. Hence it leads to a reduced effort of remeshing process. This feature makes meshfree methods a perfect candidate for incorporating moving particle formulation into fluid-structure interaction problems to account for deformable fluid domain, fluid-structure interface and largely-deformed structure. The figures shown below are an example of the mesh-update algorithm. As the 3-D cylinder is displaced, element entanglements appear near the refined area as the finite element mesh is distorted. Using the meshfree method, however, eliminate this problem. A schematic illustration of how finite element mesh and



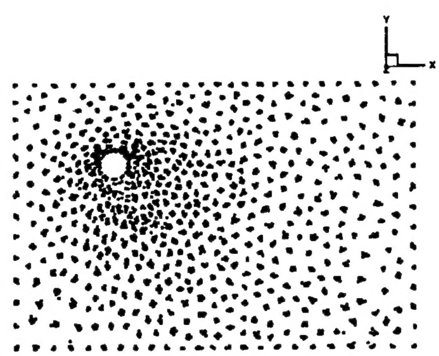
(a) Original 3-D Finite Element Mesh



(b) Undeformed Finite Element Mesh intersection in z-direction



(c) Deformed Finite Element Mesh After Mesh Update



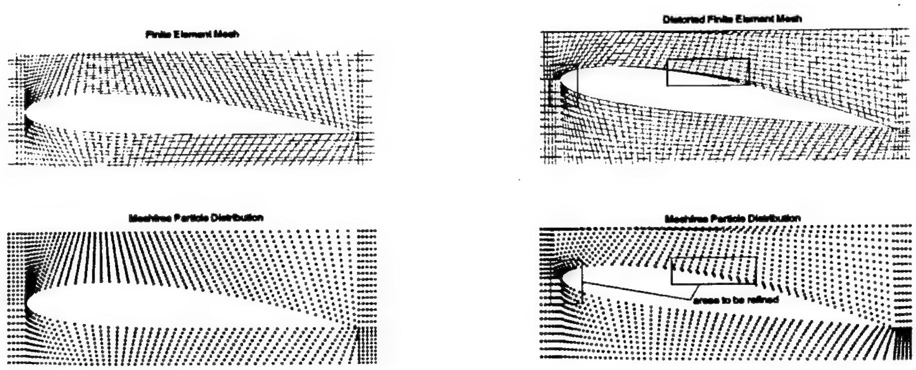
(d) Particle Distribution After Mesh Update

Figure 12: Comparison of finite element methods and meshfree methods

the meshfree moving particle distribution behave differently is shown in Figure. Severe mesh distortion occurs in the boxed area of the finite element mesh which would lead to

computation termination unless time-consuming remeshing technique is adopted; while such difficulty is greatly alleviated in the meshfree particle methods. Meanwhile, with the proposed moving particle formulation, h-adaptivity can be implemented by simply adding additional particles into the areas of interest.

The proposed approach will also take advantage of the wavelet character of meshfree approximations. The ability to capture high gradient variation in fluid and moving fluid-structure interface can be achieved by adding a sequence of wavelets to associated particles in the area of interest which leads to a p-like adaptivity (Figure 14) without the awkwardness of p-type finite element shape function construction. In addition to its simplicity, the adaptivity by meshfree moving particle method not only requires less particles compared to the finite element methods but also provides higher accuracy. It is noted that the structural deformation is of orders of magnitude larger than the boundary layer thickness, hence the elimination of a finite element mesh (i.e. meshfree) is the key to success of this multi-scale meshfree moving particle method.



(a) Original Mesh and Particle Distribution

(b) Distorted Mesh and Updated Particle Distribution

Figure 13: Comparison of finite element methods and meshfree methods

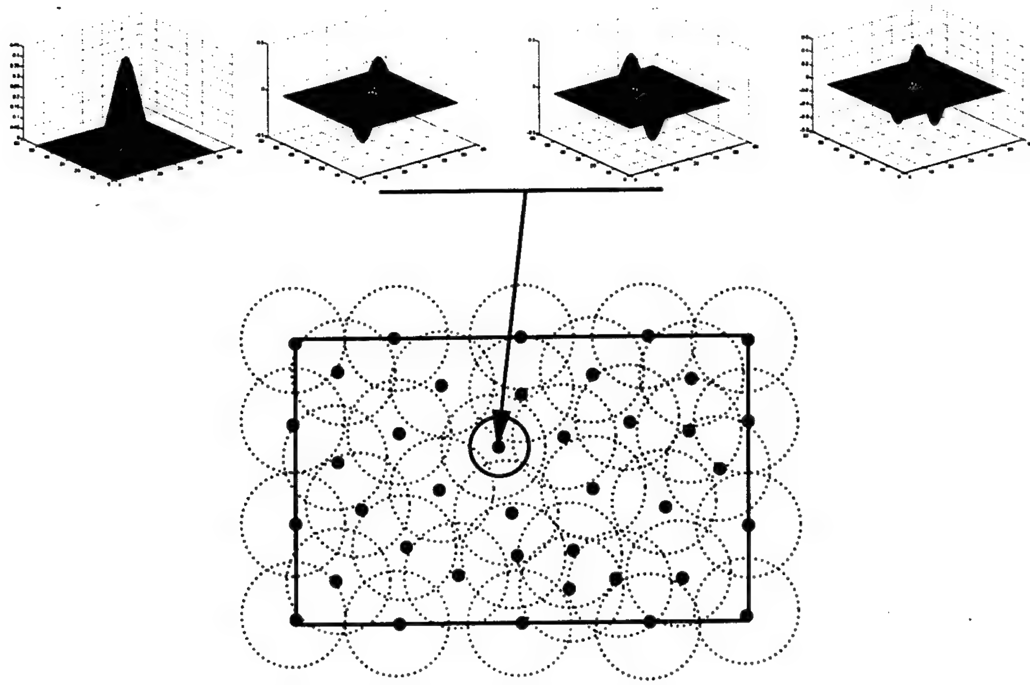


Figure 14: Wavelet adaptivity for the area of interest by meshfree methods (a close-up view of the boxed area in Figure 13)

5 Personnel Supported

Wing Kam Liu, Professor
Wei Hao, Graduate Student
Gregory Wagner, Graduate Student
Frank Günther, Graduate Student

6 Publications

[1] W. K. Liu and S. Li and W. Hao Simulations of Fluids and Solids by Multi-Scale Meshfree Methods *EPMESC VII Computational Methods in Engineering and Science, edited by Bento, Oliviera, and Pereira*, Vol. 1, 43-52, 1999.

[2] S. Li, W. Hao and W. K. Liu Numerical Simulations of Large Deformation of Thin Shell Structures Using Meshfree Methods *To appear in Computational Mechanics*, 1999.

[3] G. Wagner and W.K. Liu Turbulence simulation and multiple scale subgrid models *To appear in Computational Mechanics*, 1999.

[4] G. Wagner and W. K. Liu Application of essential boundary conditions in meshfree methods: a corrected collocation method *To appear in International Journal for Numerical Methods in Engineering*, 1999.

[5] F. Günther, W. K. Liu, D. Diachin and M. Christon Multi-Scale Meshfree Parallel Computations for Viscous, Compressible Flows *Accepted for publication in a special issue*

of Computer Methods in Applied Mechanics and Engineering, 1998.

[6] S. Li and W. K. Liu Reproducing Kernel Hierarchical Partition of Unity *Accepted for publication in International Journal for Numerical Methods in Engineering*, 1998.

[7] S. Li and W. K. Liu Synchronized Reproducing Kernel Interpolant via Multiple Wavelet Expansion *Computational Mechanics*, 21:28-47, 1998.

[8] W. K. Liu, F. Günther, W. Hao and S. Hao Multiple Scale Methods for Compressible Viscous Fluid-Structure Interaction *Army High Performance Computing Research Center Preprint 98-055*, 1998.

[9] F. Günther and W. K. Liu Implementation of Boundary Conditions for Meshless Methods *Computer Methods in Applied Mechanics and Engineering*,163:205-230, 1998.

[10] W. K. Liu, S. Jun, D. T. Sihling, Y. Chen, and W. Hao Multiresolution Reproducing Kernel Particle Method for Computational Fluid Dynamics *International Journal of Numerical Methods in Fluids*, 23:1391-1415, 1997.

[11] S. Li and W. K. Liu. Moving Least Square Reproducing Kernel Method Part III: Wavelet Packet and Its Applications *Accepted for publication in Computer Methods in Applied Mechanics and Engineering*, 1997.

[12] W. K. Liu, Y. Chen, C. T. Chang, and T. Belytschko. Advances in Multiple Scale Kernel Particle Methods. *A special feature article for the 10th anniversary volume of "Computational Mechanics"* , 18(2):73-111,June 1996.

[13] W. K. Liu, Y. Chen, S. Jun, J. S. Chen, T. Belytschko, C. Pan, R. A. Uras, and C. T. Chang. Overview and Applications of the Reproducing Kernel Particle Methods. *Archives of Computational Methods in Engineering; State of the art reviews*, 18:3-80, 1996.

[14] W. K. Liu, Y. Chen, R. A. Uras and C. T. Chang. Generalized Multiple Scale Reproducing Kernel Particle Methods. *Computer Methods in Applied Mechanics and Engineering*, 139:93-158, 1996.

7 Interaction/Transitions

7.1 Presentations at Meetings, Conferences, Seminars, etc.

- Invited Talk and visit, "Multiple Scale Meshfree Methods", US Army Corps of Engineers, Vicksburg, MS, July 16-17, 1998.
- Invited Talks at The 4th World Congress On Computational Mechanics, Buenos Aires, Argentina, June 29 - July 2, 1998. Keynote Lecture: Wing Kam Liu, "Multiple Scale Meshfree Methods By Wavelet Packages"
- INVITED TALK, Wing Kam Liu, "Overview Of Multiple Scale Meshfree Methods for Solids And Fluids,' University Of Illinois At Chicago, April 23, 1998.
- INVITED TALK, Wing Kam Liu, "Improved SPH By RKPM", Johnson Space Center, Houston, April 16, 1998.

- INVITED TALK, Wing Kam Liu, Frank Günther, and Darin Diachin, "Multi-Scale Meshless Parallel Computations for Viscous, Compressible Flows", Fourth Japan-U.S. Symposium on Finite Element Methods in Large-Scale Computational Fluid Dynamics, Nihon University, Tokyo, Japan, April 2-4, 1998.
- INVITED TALK, Wing Kam Liu, "RKPM for Fracture and Fatigue", 3rd International Conference on Fracture and Strength, Hong Kong University of Science and Technology, Hong Kong, December 9, 1997.
- INVITED TALK, Wing Kam Liu, "Overview of Meshfree Methods", Kawasaki Heavy Industries, Japan, December 5, 1997.
- INVITED TALK, Wing Kam Liu, "Computational Structural Mechanics: A Meshfree Approach", Army Research Laboratory, Aberdeen Proving Ground, MD, November 13, 1997.
- INVITED TALK, Wing Kam Liu, "Computational Structural Mechanics: A Meshfree Approach", AHPCRC, Minneapolis, MN, October 8, 1997.
- INVITED TALKS. W. K. Liu, 4th National Congress on Computational Mechanics, Hyatt Regency Embarcadero, San Francisco, August 8-10, 1997, "MRKPM for Compressible Flow -Structure Interaction", "Meshless Partition of Unity Methods", "Synchronized Convergence for Meshless Methods", "Wavelet Methods for Damage and Fracture"
- INVITED DISTINGUISH LECTURE, W. K. Liu, SHERATON ORCHID HOTEL, BIG ISLAND, HAWAII,July 8-14, 1997, "Finite Elements and Multiple Scale Methods for Composite"
- GENERAL CHAIRMAN OF MCNU'97, THE 1997 JOINT ASCE/ASME/SES CONFERENCE, NORTHWESTERN UNIVERSITY, June 29-July 2, 1997, "Overview of Multiple Scale Methods", "Application of Multiple Scale methods to Fluid-Structure Interactions", "Application of Multiple Scale Methods to Fracture and Damage and Fracture", "An 8-Node Under-integrated Element of Sheet Metal Forming"
- INVITED TALKS. W. K. Liu, Eglin Air Force Base, FL, Dr. Yen Tu and Dr. Dave Belk and their research group, May 22-23, 1997, "Multiresolution Meshless Methods for Solids, Fluids and Fluid-Structural Interaction". Discussions on mutual research initiation of transfer of the Air Force research to them.
- INVITED KEYNOTE. W. K. Liu, Hotel Herradura Resort and Conference Center, San Jose, Costa Rica, International Conference on Computational Engineering Science, May 4-9, 1997, "An Overview of Multiple Scale Methods–Its Applications to Fluids, Solids and Fluid-Structural Interactions"
- W. K. Liu, Omni, Austin Texas, Office of Naval Research Program Review, February 18-19, 1997, "Multiple Scale Methods"
- INVITED TALK. W. K. Liu, Texas Institute of Computational Applied Mathematics, January 12-15, 1997, "Multiresolution Reproducing Kernel Particle Methods"
- INVITED TALK. W. K. Liu, Sandia National Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, Computational Physics Group, Dr. Mark Christon and his research group on Wavelet Project, January 8-10, 1997, "Wavelets RKPM". Discussion of Mutual Research and Transfer of RKPM FSI technology to their group, obtained a $25K contract to work on "Multiple Scale Methods for Compressible Viscous Fluid-Structure Interaction"

- INVITED PAPERS. W. K. Liu, Hong Kong Polytechnic University, December 3-11, 1996, "RKPM for Fluid-Structure Interaction", "FE and Wavelet RKPM"
- W. K. Liu, Visit Office of Naval Research and Naval Research Laboratory, November 26, 1996, "Multiple Scale Methods for Complex Fluid-Structural Structures"
- INVITED PAPER. W. K. Liu, Second Annual Symposium on Frontier of Engineering, sponsored by National Academy of Engineering, September 18-22, 1996, Participation in group discussion
- Kawasaki Heavy Industries, and Mishibishi Heavy Industries, "Wavelet and Reproducing Kernel Particle Methods", August 23-September 2, 1996.
- Holiday Inn, Vicksbrug, Mississppi, Army Research Office and Waterway Experimental Station, "Multiresolution Meshless Methods", April 24-25, 1996.
- ARO Workshop, Waterway Experimental Station, April, 1996.
- Marquette Hotel, Army High Performance Computing Research Center, Minnesota, "Meshless Methods for CFD", March 31-April 3, 1996.
- Argonne National Laboratory, Reactor Engineering, "Wavelets and RKPM for Large Deformation Analysis", February 21, 1996.
- ASME WAM Meeting, November, 1995.
- ASME PVP Conference, July, 1995.
- The 3rd U.S. National Congress on Computational Mechanics, Dallas, June, 1995.

7.2 Transitions

- Dr. Mark Christon of Sandia National Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, Computational Physics R & D Group (phone number: 505-844-8520): continues his support on our multiple scale RKPM development. Mr. Darin F. Diachin, a graduate student, supported by the Sandia National Laboratory, is currently working with Dr. Mark Christon at Kirtland Air Force Base from June 18, 1998 to September 29, 1998. His duty is to improve the pilot multiple scale RKPM computational fluid dynamics code at the Kirtland Air Force lab. In addition, Dr. Christon and Mr. Diachin are collaborating with researchers at Argonne National Lab on converting our CFD computer code into parallel computations using the ASCI Red machine with thousands of processors.
- Ford Motors (Dr. Sing Tang, Manufacturing System Department, Dearborn, MI, phone number: 313-323-1144) continues to support our research on "multiple-quadrature 8-node hexahedral finite element and multiple scale meshfree methods" by providing an additional cash gift of $48K to Northwestern University under the direction of Wing Kam Liu (co-investigator, Professor Cao) in March, 1998. They are in particular excited about the performance of our element as well as the meshfree approach.
- Eglin Air Force Base, developing a white paper
- Graduate student Gregory Wagner is being supported by 3-year DoD fellowship to work on multiple scale modeling of turbulent flows.
- Argonne National Laboratory, Dr. Aziz Uras

- The University of Iowa, Dr. J. S. Chen
- Dagonet Software, Air Force Phillips Laboratory, 2904 La Veta Dr. NE, Albuquerque, NM 87110-3110, Dr. Lou Baker
- Ontario Hydro Technologies, Ontario, Canada
- The University of Michigan, Dr. G. Hulbert
- Centric Engineering, Santa Clara – FE code Spectrum, fluid-structure interaction, Dr. T. J. R. Hughes
- Century Dynamics – SPH and FE code Autodyn 2D, Colin Hayhurst, Great Britain

8 New Discoveries, Inventions, or Patent Disclosures

- Recent discovery of a correction function for restoring consistency in kernel methods including smooth hydrodynamics methods (SPH).
- Novel construction of synchronized convergence for Wavelet Reproducing Kernel Particle Methods (WRKPM).

9 Honors/Awards

Liu, Wing Kam:

1998 Fellow of International Association of Computational Mechanics

1997 Fellow of American Academy of Mechanics

1996 President Elect (2000-) of U.S. Association for Computational Mechanics

1995 Gustus L. Larson Memorial Award of American Society of Mechanical Engineers, presented at the 1995 International Congress & Exposition, San Francisco, November, 1995

1995 Fellow of U.S. Association for Computational Mechanics

1993 Fellow of American Society of Civil Engineers

1990 Fellow of American Society of Mechanical Engineers

1989 Thomas J Jaeger Prize, International Association for Structural Mechanics in Reactor Technology

1985 Pi Tau Sigma Gold Medal of American Society of Mechanical Engineers

1983 Ralph R. Teetor Educational Award of American Society of Automotive Engineers

1979 Melville Medal of American Society of Mechanical Engineers

REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-00-

0185

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 2000

3. REPORT TYPE AND DATES COVERED
FINAL TECHNICAL REPORT 1 May 96 - 30 Sep 99

4. TITLE AND SUBTITLE
MULTIRESOLUTION ANALYSIS OF COMPRESSIBLE VISCOUS FLOW-STRUCTURE INTERACTION

5. FUNDING NUMBERS
F49620-96-1-0171

61102F
2302/DX

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801 N. RANDOLPH STREET, ROOM 732
ARLINGTON, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Since fluid-structure interaction requires solid mathematical modeling of the various physical phenomena of solids/structure and fluids. The research efforts reported here have been focused on the development of multiple-scale Reproducing-Kernel Paricle Mehtods (RKPM) which possess a few remarkable technical advantages from a computational mechanics point of view, such as mesh-free interpolation functions and superior accuracy and convergence rate with stabilization. Most importantly, with the inherent multiresolution analysis capability, RKPM isused to further investigate the physical nature of fluid-structure interaction problems in a way that the system response can be decomposed into multiple frequencywave number bands for a better represphysics.

14. SUBJECT TERMS

15. NUMBER OF PAGES
15

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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